CKU-5C/A ROCKET CATAPULT ACES II SLED TEST PROGRAM

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ABSTRACT

The CAD/PAD Department at the Indian Head Division, NSWC in conjunction with the Joint CAD/PAD Program, conducted a series of five ACES II ejection seat tests using the CKU-5C/A rocket catapult which has been developed to replace the current CKU-5B/A rocket catapult. The system tests included F-15, F-16, and A-10 configuration ACES II ejection seats with large (JPATS Case 6) and small (LOIS) anthropometric manikins that represented test conditions to evaluate the system compatibility of the revised rocket catapult design.

Figure 1. ACES II A-10 System Test

Highlights of the system sled tests results, conducted by Goodrich AIP at the Hurricane Mesa Test Facility, and the Holloman Air Force Base High Speed Test Track are reviewed and key results presented. These results indicate acceptable system performance of the ACES II ejection seat with the upgraded CKU-5C/A rocket catapult. Figure 1 is a test sequence photo from the A-10 CKU-5C/A system test.

INTRODUCTION

The CKU-5 Rocket Catapult is used in the A-10, F-15, F-16, F-117, F-22, B-1, and B-2 aircraft as the primary propulsion for the aircrew escape ejection system. This rocket catapult is a combination device that first ejects the seat and aircrew member from the aircraft cockpit and then propels the seat and aircrew member to a height necessary for safe parachute recovery. Figure 2 shows the rocket catapult installed on the ACES II ejection seat.

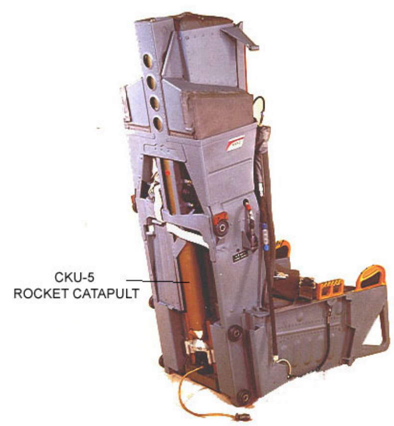

Figure 2. ACES II Ejection Seat with CKU-5 Rocket Catapult

Indian Head Division (IHDIV), NSWC in conjunction with the Joint CAD/PAD Program Office has developed an improved rocket catapult for the ACES II ejection seat. The CKU-5C/A rocket catapult has been developed and qualified to provide an upgraded design that features a replacement hydroxyl-terminated polybutadiene (HTPB) propellant configuration in both the catapult impulse cartridge (CCU-22) and sustainer rocket. All changes to the unit are internal and have no impact on installation, handling, or use in the ACES II.

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The Qualification program included system sled tests to supplement the complete rocket catapult delta-qualification. While the system sled tests provided a general system level assessment of the upgraded CKU-5C/A, the component qualification program addressed the full capability of the revised design to function across the range of environmental conditions and and provided verification of ballistic performance acceptability.

CKU-5C/A DESIGN, DEVELOPMENT AND QUALIFICATION

Development tests of the CKU-5C/A Rocket Catapult were conducted in several series of static firing tests for both the CCU-22B/A impulse cartridge and the complete rocket catapult. Some minor adjustments to the design were found to be necessary, including changes to the auxiliary igniter. The final development configuration introduced an expanded volume igniter enclosure that permitted additional ignition material to be packaged in the igniter, and eliminated lengthened ignition delays that were observed during early development evaluations. [1]

The performance of the CKU-5C/A Rocket Catapult satisfied the same specification requirements of the CKU-5B/A that it replaced. A comparison of thrust versus time is shown in Figures 3 and 4. At the Lot Acceptance Test weight of 375 pounds, the CKU-5C/A catapult performance produces higher separation velocities at –65 °F and lower peak thrusts at 165 °F. The rocket motor performance at the temperature extremes will remain virtually identical, giving similar resultant thrust, action time and impulse.

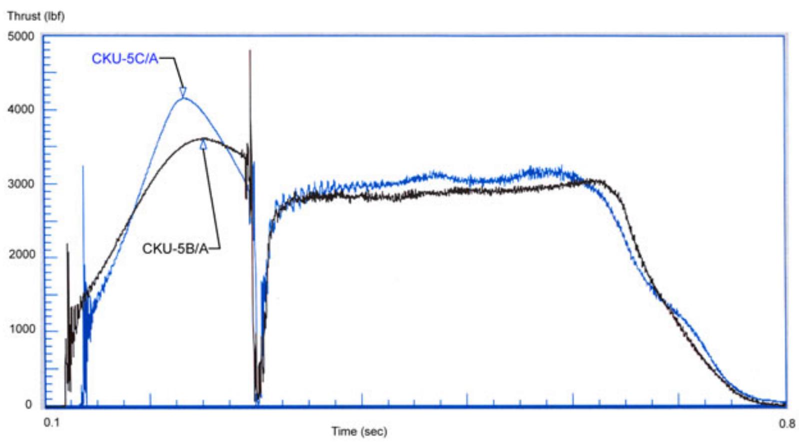

Figure 3. Comparison of CKU-5C/A and CKU-5B/A Thrust at -65F

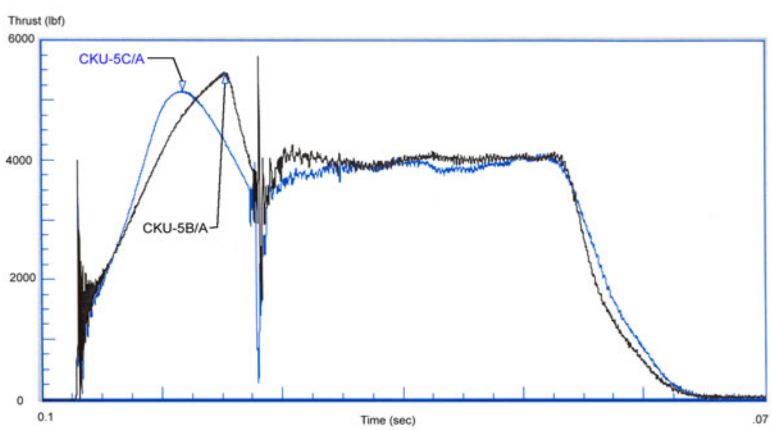

Figure 4. Comparison of CKU-5C/A and CKU-5B/A Thrust at 165F

The qualification program for the CKU-5C/A Rocket Catapult was modeled after the requirements of MIL-P-83126A, the Design Specification for Aircrew Escape Propulsion Systems. Forty-seven (47) complete rocket catapults and twenty-eight (28) CCU-22B/A cartridges were tested in the program that included environmental testing and ballistic static firing tests at –65 °F, 77 °F and 165 °F using propelled weights of 300, 375 and 484 pounds. Qualification test results indicated all requirements were satisfied. In addition to accelerated aging and 84 day high temperature storage tests completed in the qualification test series, an 18 unit Type Life Study was initiated which will further evaluate the CKU-5C/A service life performance.

SLED TEST PROGRAM

The system sled test program consisted of five ACES II ejection seat tests, using three aircraft seat configurations and two test track facilities. Four of those tests were conducted by AIP Goodrich at their Hurricane Mesa Test Facility, located in Southern Utah, and used an F-15 forebody sled. General Dynamics AIS provided manikin support for the F-15 series tests. One test, using the A-10 aircraft sled and the A-10 ACES II configuration seat was conducted by the Air Force 846th Test Squadron at the Holloman AFB High Speed Test Track near Alamogordo, New Mexico. Table 1 provides a summary of the system test configurations.

Table 1. CKU-5C/A Sled Test Matrix

TEST	SLED	COCKPIT	TEST FACILITY	SEAT	KEAS	MODE	MANIKIN	CANOPY
1	F-15	FWD	Hurricane Mesa	F-15	0	1	JPATS Case 6	No
2	F-15	FWD	Hurricane Mesa	F-15	0	1	LOIS	Thru Canopy
3	A-10	-	Holloman AFB	A-10	0	1	JPATS Case 6	Thru Canopy
4	F-15 MOD	AFT	Hurricane Mesa	F-16	600	3	LOIS	No
5	F-15	FWD	Hurricane Mesa	F-15	600	3	JPATS Case 6	No

Table 2. Summary of System Test Results [2] [3]

Test	Test Velocity (KEAS)	Manikin	Man/seat mass (lbm)	Max DRI	MDRC	Trajectory Height (ft)
1. HMTF 773	0	Large (Case 6)	454.5	8.5	0.48	120
2. HMTF 774	0	Small (LOIS)	313.4	12.4	0.68	175
3. 96E-A1	0	Large (Case 6)	439.7	8.2	0.46	140
4. HMTF 775	608	Large (Case 6)	483.0	9.0	1.22	45
5. HMTF 778	638	Small (LOIS)	330.0	15.2	1.96	75

The test configurations included use of expanded range test manikins, the large male JPATS Case 6 manikin, weighing 245 lbs nude, and the small female LOIS manikin weighing 103 lbs nude. Testing with these expanded range manikins provided a system level assessment at conditions exceeding the original design allocation yet enabled an assessment of design margin for the expanded population that current ACES II improvements are being tested at. All manikins utilized 40 channel data acquisition systems (DAS) and standard instrumentation. Manikin preparation and data acquisition support was provided by General Dynamics AIS for the HMTF test series, and by the 746th Test Squadron, Holloman AFB for the A-10 test.

The system test points focused on conditions chosen to challenge the rocket catapult performance, including through-the-canopy for both the F-15 and A-10 aircraft backup mode ejection scenarios, as well as general static (zero/zero) and maximum speed (600 KEAS) ejection speeds.

Test 1 – Static F-15 Large Occupant
This test provided an evaluation of the performance of the rocket catapult at zero velocity and maximum ejected weight.

Test 2 – Static F-15 Through-the-Canopy
This test provided an assessment of the F-15 aircraft through-the-canopy back up mode performance, with worst case DRI conditions of lightest ejected weight combined with canopy penetration resistance.

Test 3 – Static A-10 Through-the-Canopy
This test provided an assessment of the A-10 aircraft through-the-canopy back up mode performance, with the maximum ejected weight combined with canopy penetration. The A-10 seat configuration includes a different canopy breaker configuration than the F-15 version, and was included in the test matrix. The heavy weight occupant was chosen since the original A-10 through-the-canopy test used the large manikin, although in that case a 210 lb 95th percentile manikin was used. Using the 245 lb Case 6 manikin in the CKU-5C/A test provided additional verification of design margin.

Test 4 – 600 KEAS F-15 Large Occupant
In this test, high speed maximum aerodynamic pressure conditions were combined with heaviest ejected mass.

Test 5 – 600 KEAS F-16 Seat Small Occupant
In this test, high speed maximum aerodynamic pressure conditions were combined with lightest ejected mass and the F-16 seat and rail configuration ejected from the F-15 fuselage sled.

Figure 5. F-15 Forebody with Canopy

F-15 SLED TESTS

Four of the five CKU-5C/A tests were conducted from the F-15 forebody sled at the Hurricane Mesa Test Facility (HMTF). Two static tests (Tests 1 and 2) and one dynamic test (Test 5) were conducted with the F-15 seat configuration. The test seats included the latest modifications to the seat configuration, including 600 Knot structural upgrades, and in some cases piggyback testing of limited versions of leg and arm restraint systems under evaluation for the ACES II. Test 4 (conducted at the end of the series to facilitate cockpit conversion) used an F-16 ACES II ejection seat and rails installed in the rear crewstation of the F-15 sled. Figure 5 shows the pretest configuration of the sled and seat assembly for Test 2 (through-the-canopy).

In order to isolate any influences of the restraint system actuation, with its passive lanyard loading that coincided with catapult stroke, in all but one test the complete system was pre-positioned with the lanyards detached. Test 5

(600 KEAS Case 6) used the leg portion of the lanyard actuation system for its deployment. The pretest condition of the seat and manikin assemblies for Tests 1 and 2 are shown in Figures 6 and 7, respectively, depicted during CG/MOI measurements.

Figure 6. Large Case 6 Manikin in F-15 ACES II

Figure 7. Small LOIS manikin in F-15 ACES II

A-10 SLED TEST

The 846th Test Squadron at Holloman AFB conducted Test 3, a through-the-canopy static test of the A-10 configuration. The test configuration was the standard A-10 ACES II ejection seat with no upgrades or piggybacked test modifications. The canopy transparency was marked with a 6 in x 6 in grid pattern for identification of fracture details as determined necessary. The starting seat height position was set between full down and neutral due in part to interference with sled instrumentation. Despite concerns over the fit of the large Case 6 manikin into the crewstation, adequate clearance was still maintained between the top of the manikin helmet and the transparency, and contact was initiated first between the seat breakers and the canopy as intended. Figure 8 is a pre-test photograph of the A-10 sled with seat and manikin installed.

Figure 8. A-10 Forebody at Holloman AFB

SYSTEM TEST RESULTS

In all tests, the system tests resulted in successful ejection performance and manikin recovery that were typical of ACES II performance. Table 2, provides a summary comparison of key test results for the test series. Adequate trajectory height and typical Dynamic Response Index (DRI) and Multi-axial Dynamic Response Criteria (MDRC) were achieved, although in some cases trajectory height was lower than expected.

Figure 9. CKU-5C/A Test 2 (HMTF 774)

Test 5 (HMTF F-15 Case 6 600 KEAS) exhibited a noticeably lower than expected trajectory, but still with acceptable recovery of the manikin. Post test examination revealed that the seat rails failed structurally at tip-off,

apparently due to fatigue accumulated over repeated reuse during repeated sled testing. It was also observed that the leg-well leg restraint system with its lanyard loading retarded the acceleration of the seat during the catapult stroke, and reduced the separation velocity. Each of these phenomenons may have had some effect on the system performance and is under further study.

Figure 10. CKU-5C/A A-10 Test 3 (96E-A1)

For both the F-15 (Test 2) and A-10 (Test 3) through-the-canopy tests, the performance of the overall system was acceptable, and showed no noticeable effect on the catapult performance. Acceptable acceleration and DRI were maintained during the canopy penetration, and a more than adequate altitude was achieved for safe manikin recovery. Figure 10 shows the canopy penetration during the A-10 Test 3. Figure 11 shows the fired CKU-5C/A following completion of Test 1.

Figure 11. Test 1 Post Test Condition with CKU-5C/A

CATAPULT PRESSURE MEASUREMENT

Supplementing standard instrumentation for all tests were pressure transducers measuring catapult ballistic pressure. Although there is no specification requirement for catapult pressure, its measurement provided additional evaluation of the catapult phase performance of the CKU-5C/A for comparison of system level performance with static ballistic test results. It also provides the most direct indication of the actual internal forces generated by the catapult during the ejection.

Catapult pressure was measured at the retainer outlet fitting at the top of the CKU-5C/A where catapult gas pressure is routed to the recovery sequencer for initiation of its thermal batteries. A custom tee fitting, instead of the standard elbow fitting was used at the CKU-5C/A to gas line interface so that a close coupled Sensotec Model S pressure transducer could package into the space at the top of the ACES II smokestack structure. The test configuration is shown in Figure 12. The manikin DAS recorded the catapult pressure data.

A comparison of the catapult pressure measurement results is shown in Figure 13. Also included for comparison are the results of two tests of the CKU-5C/A catapult (CCU-22B/A impulse cartridge) tests conducted on the horizontal test stand at IHDIV, NSWC. Test ID 9378 used an ejected mass of 300 lb, and Test ID 9387 used a mass of 484 lb, both conducted at 77˚F. The pressures recorded on the system sled tests were lower than those on the horizontal catapult tests.

Figure 12. Catapult Pressure Cell and Tee Fitting

CKU-5C/A Catapult Pressure

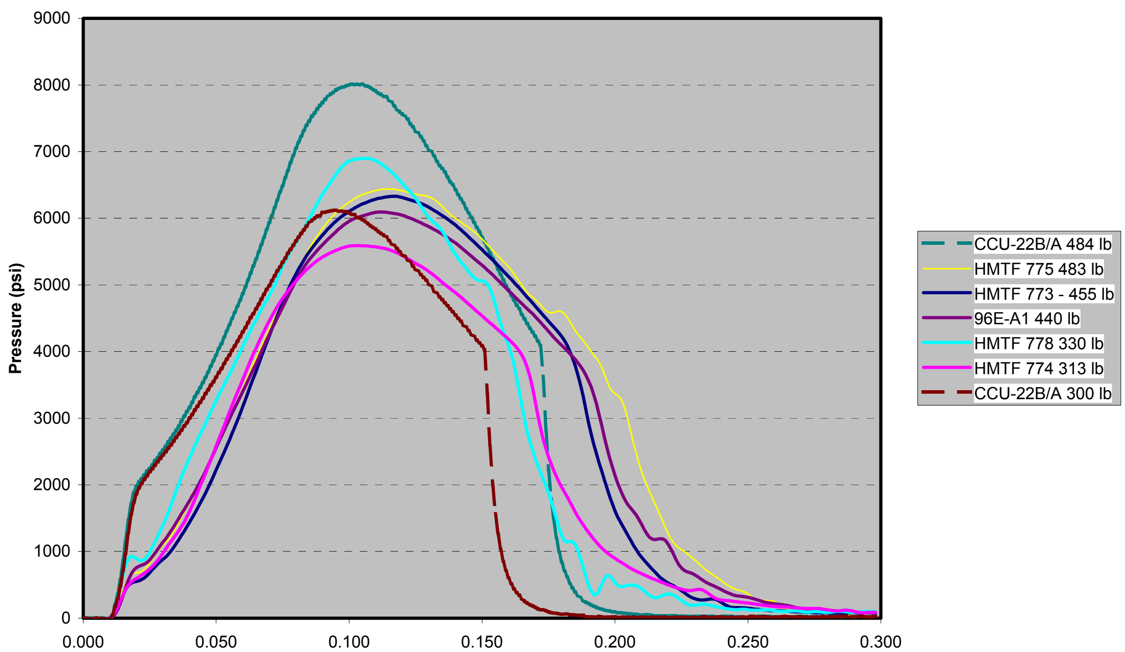

Figure 13. Comparison of Catapult Pressure Results

The causes of this difference continue to be investigated, although some can be attributed to differences between the catapult test configuration and the complete seat system. One notable difference is the initial pressure rise behavior, which may be attributed to the effects of the sequencer gas line and thermal battery initiation on the actual ACES II system, which is not represented on the catapult test stand setup. A difference in initial rate of pressure rise can subsequently alter the remainder of the pressure versus time relationship during the catapult function.

POST TEST HARDWARE ASSESSMENT

Each of the CKU-5C/A test articles used in the system tests was subjected to a post test marginality of success (MOS) inspection was conducted immediately following each test to identify any evidence of marginal conditions, including evidence of abnormal gas leakage or erosion. These results were used to evaluate any differences that were evident with the improved rocket catapult design. Some minor conditions of erosion were noted which had no apparent effect on the ballistic performance of the rocket catapults. These findings will be evaluated in total with the MOS results of the component qualification program to identify the focus of any future improvements.

CONCLUSIONS

System test results were successfully collected for each of the CKU-5C/A system sled tests in the test series. The system tests resulted in successful ejection performance and manikin recovery that were typical of ACES II performance. These results combined with the acceptable specification performance of the component qualification program indicate that the CKU-5C/A rocket catapult is an acceptable replacement for the existing CKU-5B/A design.

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BIOGRAPHIES

Craig Wheeler is a Senior Engineer and the PAD Technologist at the Indian Head Division, Naval Surface Warfare Center, responsible for Aircrew Escape Propulsion Systems technology. He received a BS degree in Mechanical Engineering from the University of Maryland in 1979. He has 24 years experience in the design, development, testing and manufacturing of propulsion devices for aircrew escape systems, including rocket motors, rocket catapults, and advanced technology controllable propulsion systems.

Milton Reese is a Project Engineer at the Indian Head Division, Naval Surface Warfare Center where he supports Product Improvement Programs (PIP) for the CAD/PAD Department. A graduate of Embry-Riddle Aeronautical University, he has 3 years experience in the design and analysis of PAD devices for aircrew escape systems.

Thomas Briscoe is an Engineering Technician at the Indian Head Division, Naval Surface Warfare Center. Since joining the Indian Head team in 1988, he has worked with CAD/PADs, first in CAD/PAD production, then in CAD Test where he performed non-destructive testing and earned his level two certification in ultrasonic inspection. He currently works in the CAD/PAD Department in the Development Branch were he works on various (PIP) Product Improvement Programs, including the CKU-5C/A.